<u>RTCA Special Committee 186, Working Group 5</u>

<u>ADS-B UAT MOPS</u>

<u>Meeting #10</u>

Description of the Receiver Model for Multi-Aircraft UAT Simulations

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SUMMARY

The following describes the UAT receiver model, for receive bandwidths of 1.2 MHz and 0.8 MHz, used for multi-aircraft network performance modeling at JHU/APL. The model is based on measured bit error performance of Pre-MOPS UAT units.

Pre-MOPS UAT Receiver Model

Measured Data

Measurements of the Bit Error Rate (BER) receive performance were made on two “Pre-MOPS” UAT transceivers, one with a nominal 1.2 MHz bandwidth and one with a nominal 0.8 MHz bandwidth. Simultaneous measurements were made while the same input signal was applied to both units. The input signal consisted of a Signal of Interest (SOI), from a nominal 1.5 MHz bandwidth UAT transceiver, summed with the following interference signals:

1. No external interference (internal receiver noise only). SOI level was varied to achieve various Signal-to-Noise Ratios (SNRs). Note that SNR depends on the noise bandwidth used, which will be defined later in this paper.
2. White Gaussian interference. SOI level was varied to achieve various SNRs.
3. A single UAT (1.5 MHz bandwidth) interferer. The levels of both SOI and interferer were independently varied to achieve various SNRs and various Interference-to-Noise Ratios (INRs).
4. A simulated combination of multiple UAT (1.5 MHz bandwidth) interferers. An Arbitrary Waveform Generator (AWG) produced these combination signals by playing back a variety of input data files. The input data files were generated from a set of single-UAT files recorded by a digital oscilloscope. These files were adjusted in level, offset in time and summed together to create the multi-UAT scenarios of interest, specifically:
    a. Two UATs, both at the same level, and at various INRs.
    b. Two UATs at high INR and at various relative levels.
    c. Three, five and ten UATs, all at the same level and at high INR.

    (As a check on the fidelity of the simulation, a single UAT at high INR was also simulated and measured and the BER was compared with the corresponding BER measured using an actual UAT at high INR.)
5. A DME interferer emitting pulse pairs with 12-usec separation. DME signals at two frequencies were used, at the SOI center frequency and one MHz above. The level of the SOI was varied to achieve a wide range of Signal-to-Interference Ratios (SIRs). The variation of BER with time during and shortly after the DME pulse pair was measured.
6. A Link 16 interferer, at various frequencies, at the SOI center frequency, three MHz higher, 6 MHz higher and so on up to 21 MHz higher. The level of the SOI was varied to achieve a wide range of Signal-to-Interference Ratios (SIRs). The variation of BER with time during and shortly after the Link 16 pulse pair was measured.

Model Assumptions

Based on the above BER measurements, a computer program (the "UAT BER Model") was designed to estimate Pre-MOPS UAT BER performance under arbitrary combinations of UAT, DME and Link 16 interference. The UAT BER Model is to be incorporated within a Multi-Aircraft UAT Simulation, which uses the BER estimates to evaluate the reception success of UAT messages.

The following simplifying assumptions were made in the UAT BER Model:

1. The variation of BER with Signal-to-Interference-Plus-Noise Ratio (SINR) for any given interference scenario is specified by just three parameters, B0, B1 and B2. In terms of the variable $\log_{10}(-\log_{10}(2*BER))$, called "llBER" in the following, every BER(SINR) relationship is specified by a 3-segment piecewise linear llBER Vs. SINR curve (for SINR specified in dB), as shown in Figure 1. The parameters B1 and B2 are the SINR values at the llBER values of -0.5 for the first segment and +0.5 for the 3rd segment. The 1st and 3rd segments intersect at SINR = B0. The second segment simply rounds off the knee at B0 by connecting the points at llBER = -0.1 and +0.1. The corresponding BER Vs. SINR curve is shown in Figure 2.
2. For multiple UAT interferers, the BER is determined only by the SINR, the INR, and the difference in level, dI, between the 2 strongest UAT interferers. If INR<<0 (INR specified in dB), BER is unaffected by dI. If there are more than two simultaneous UAT interferers, the 3rd strongest and all weaker ones have the same impact as noise sources of the same power levels (measured in a noise bandwidth yet to be specified), so their powers are understood to be included in the noise term for computing INR. The interference term in INR is the power sum of the two strongest interferers only.
3. For combined Gaussian noise and multiple UAT interference, the variation in each of the parameters B0, B1 and B2 with INR for any given value of dI follows a 4-parameter sigmoid curve of the form $B = a + b \cdot \frac{INR - d}{\sqrt{c^2 + (INR - d)^2}}$, where the parameters a, b, c and d are given by:
   - a = {B(INR>>0) + B(INR<<0)}/2,
   - b = {B(INR>>0) - B(INR<<0)}/2,
   - d = INR at which B = a, and
   - c = b divided by the slope of the B(INR) curve at INR = d.

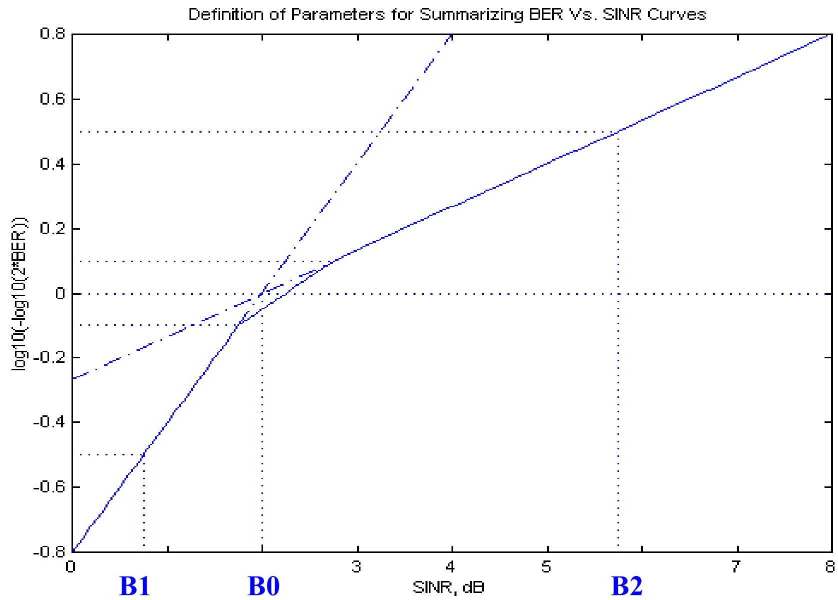

Figure 1. Assumed Piecewise Linear llBER Vs. SINR Curve

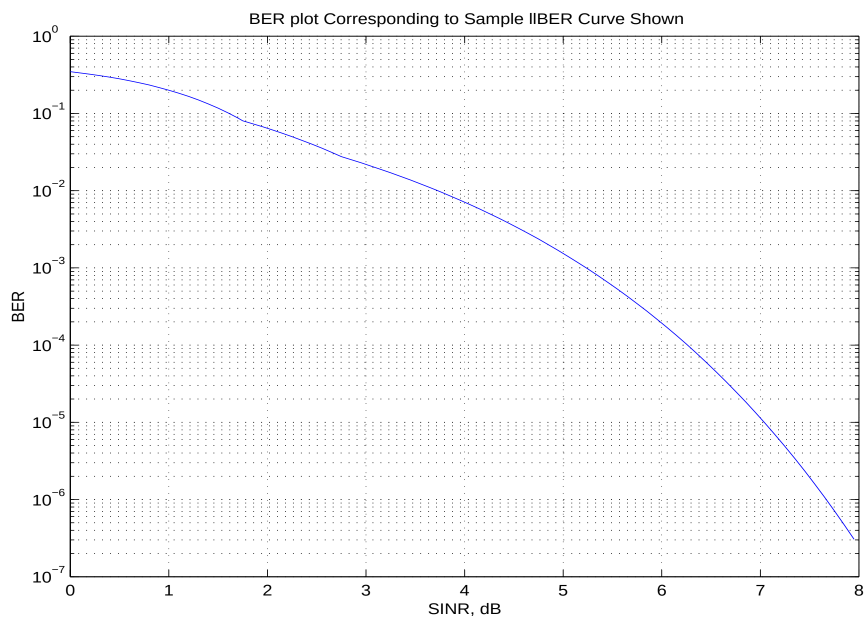

Figure 2. BER Vs. SINR Curve Corresponding to Figure 1

4. For combined Gaussian noise and multiple UAT interference, the variation in each of the parameters B0, B1 and B2 with dI follows a 3-parameter sigmoid curve of the form $B = a + b \cdot \frac{dI}{\sqrt{c^2 + dI^2}}$, where the parameters a, b, and c are given by:
   a = B(dI=0),
   b = {B(dI>>0) - B(dI=0)}, and
   c = b divided by the slope of the B(INR) curve at dI = 0.

   Assumptions (2, 3 and 4) together mean that the any of the three B parameters for any combination of Gaussian noise and multiple UAT interference may be specified by eight parameters (a0,b0,c0,d0 to describe B(INR) when dI>>0; b1,c1,d1 to describe B(INR) when dI=0; and c2 to describe B(dI) when INR>>0. The requirement of continuity of B(INR,dI) determines the remaining parameters:
   a1 = (a0 - b0) + b1,
   a2 = B(INR) for dI = 0, and
   b2 = B(INR) for dI>>0 - a2.

5. The BER impact of combining DME with other UAT interference and with receiver noise is the same as if the DME interference on any bit were replaced by an additional UAT interferer with a level such that it alone would produce the same BER as the DME interference alone.
6. The BER impact of combining Link 16 with other UAT interference and with receiver noise is the same as if the Link 16 interference on any bit were replaced by an additional Gaussian noise interferer with a level such that it alone would produce the same BER as the Link 16 interference alone.

With the above assumptions, BER is determined for every combination of Gaussian noise, multiple UAT, DME and Link 16 interference, by SINR, INR and dI, as defined above, together with 24 parameters. These parameters are then determined for each of the two Pre-MOPS UAT receive bandwidths as the values that best fit the measured Gaussian noise plus UAT interference data.

One additional parameter, the appropriate noise bandwidth must also be specified. This is conveniently represented as dN, the increase in effective noise power over that computed for a 1 MHz bandwidth. Initially, dN was chosen to equalize the SNR required for a given BER when interference was pure Gaussian noise with the SIR required when interference was ten equal-power UAT interferers. Subsequently, it was found that a better overall fit could be obtained with dN about 2 dB higher (bandwidth 60% larger). The dN values used are +1.5 dB for the 1.2 MHz bandwidth UAT and 0 dB for the 0.8 MHz bandwidth UAT.

Model Accuracy

Figures 3 through 10 show the measured and modeled BER Vs. SINR curves for five subsets of the measured data and for both UAT receive bandwidths. Figures 11 and 12 show the BER modeling error for all the Gaussian noise plus UAT interference data so as to indicate the equivalent power error in dB. The BER-to-power curve used for Figures 13 and 14 is the curve appropriate for pure Gaussian noise interference. With this measure, it can be seen that most of the data is modeled to + or – 1.5 dB accuracy.

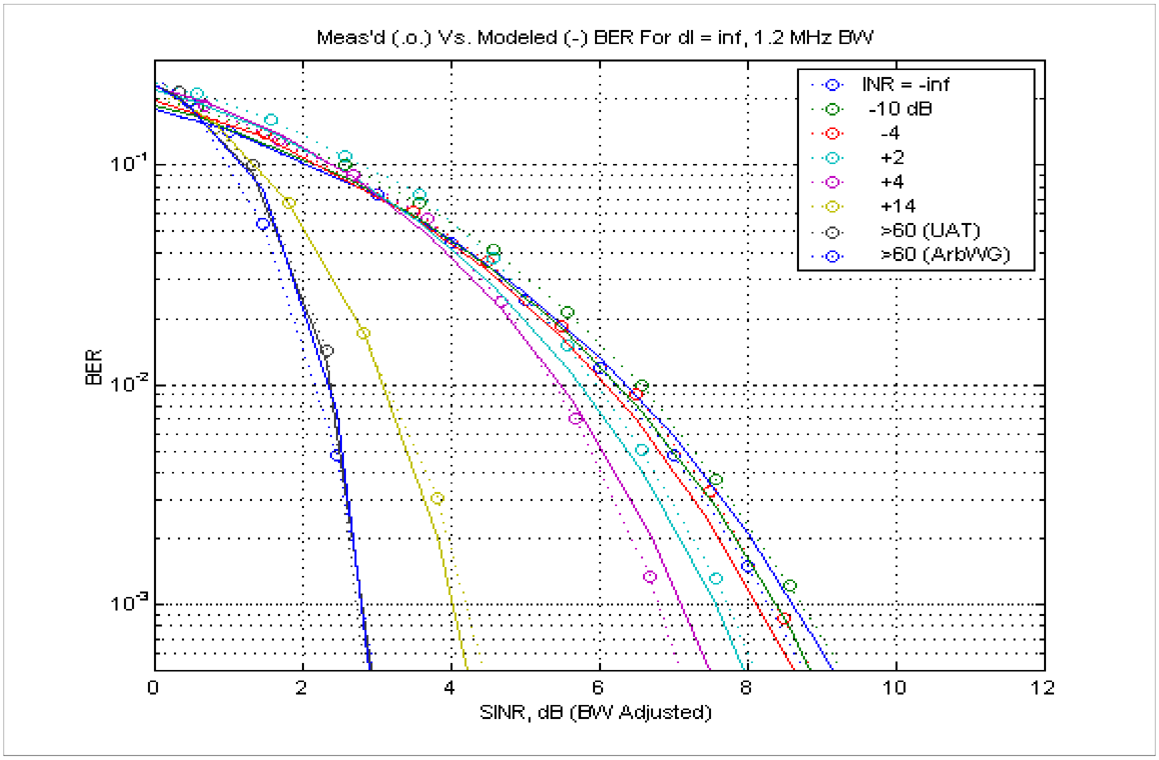

Figure 3. Gaussian Noise + Single UAT, 1.2 MHz Receiver

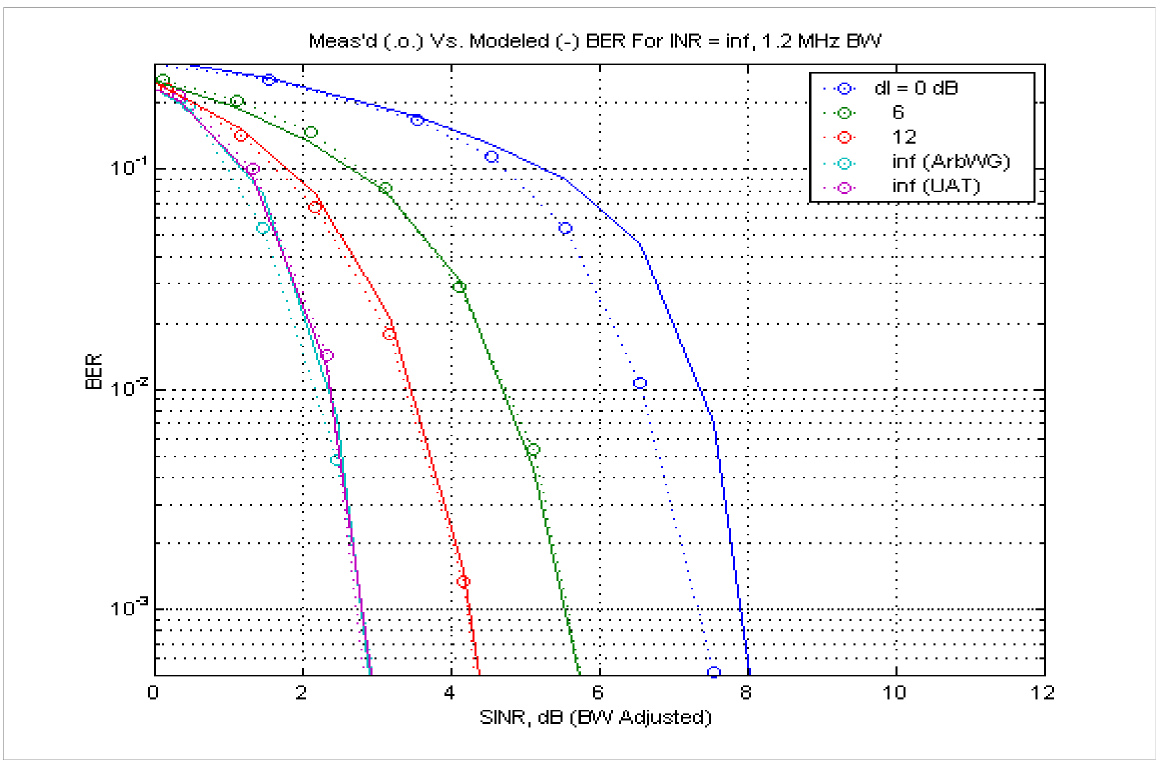

Figure 4. Two Unequal UATs, INR >> 0 dB, 1.2 MHz Receiver

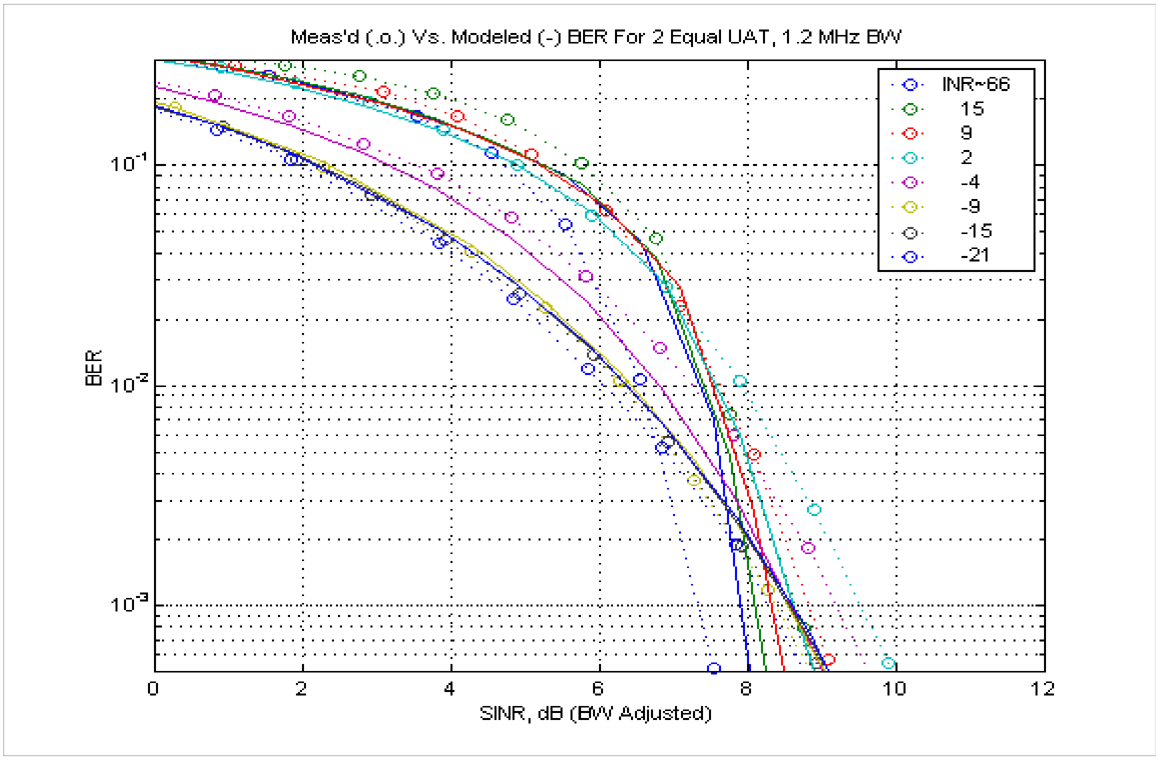

Figure 5. Gaussian Noise + Two Equal UATs, 1.2 MHz Receiver

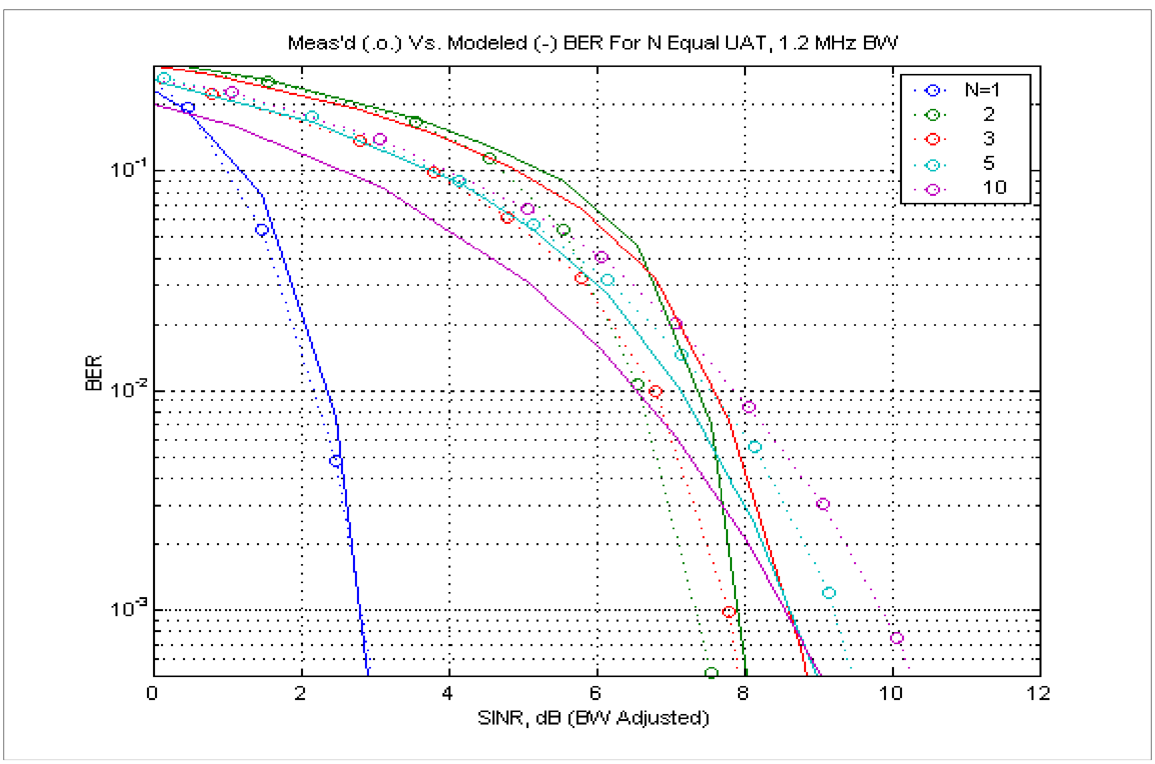

Figure 6. N Equal UATs, INR >> 0, 1.2 MHz Receiver

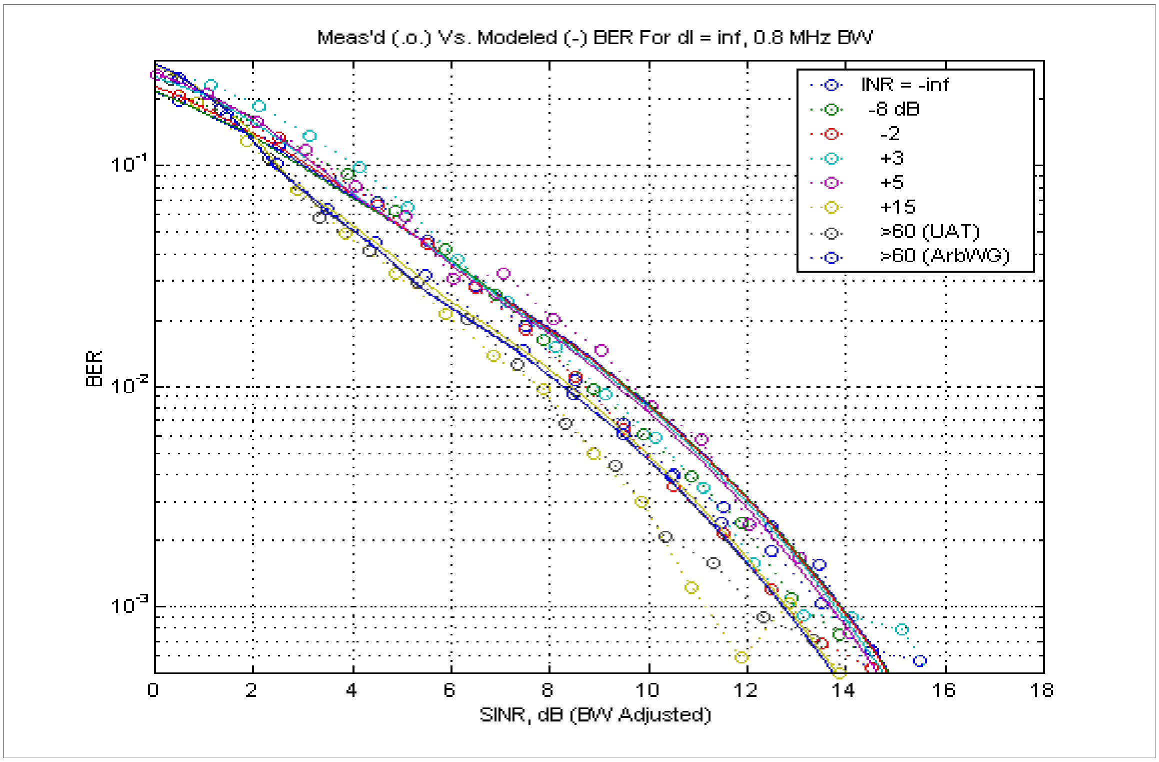

Figure 7. Gaussian Noise + Single UAT, 0.8 MHz Receiver

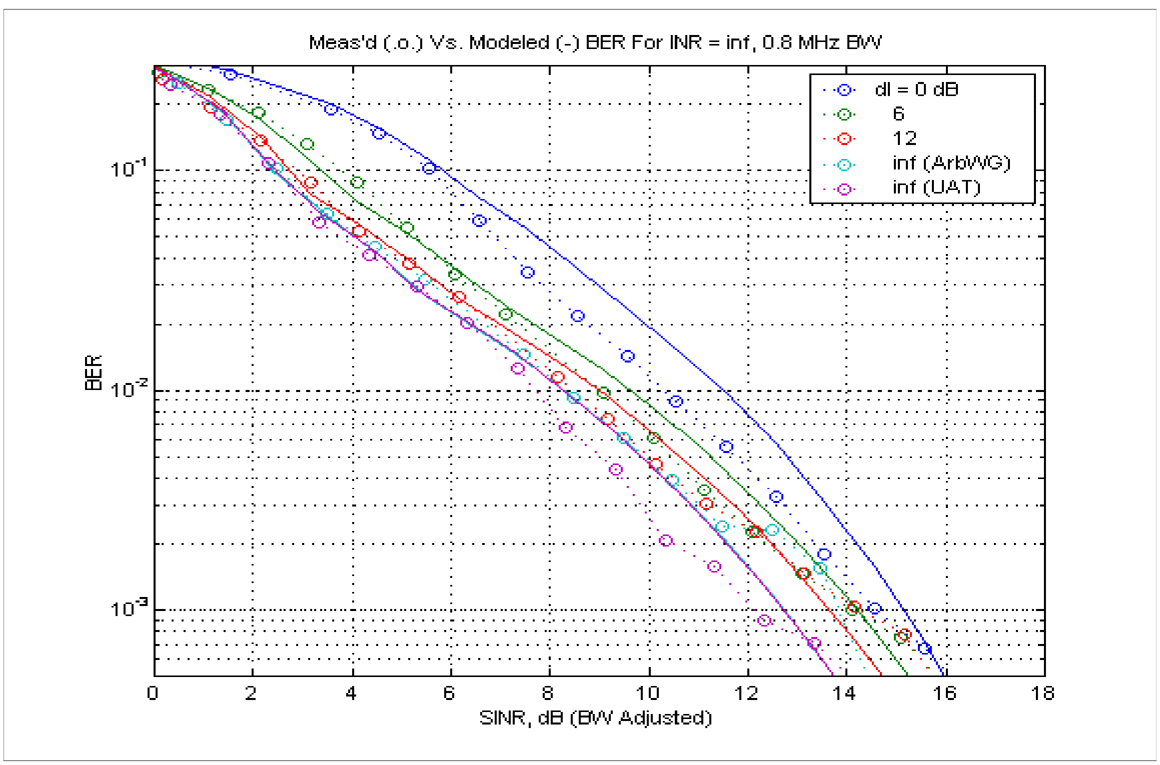

Figure 8. Two Unequal UATs, INR >> 0 dB, 0.8 MHz

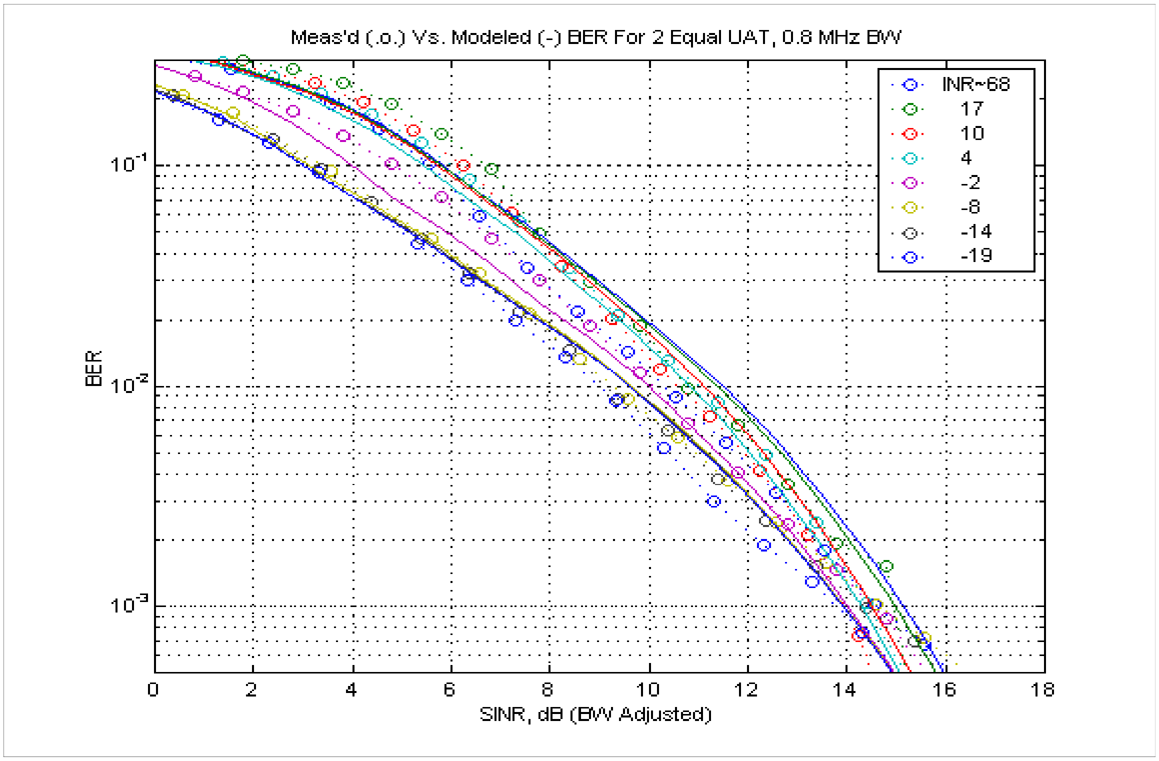

Figure 9. Gaussian Noise + Two Equal UATs, 0.8 MHz Receiver

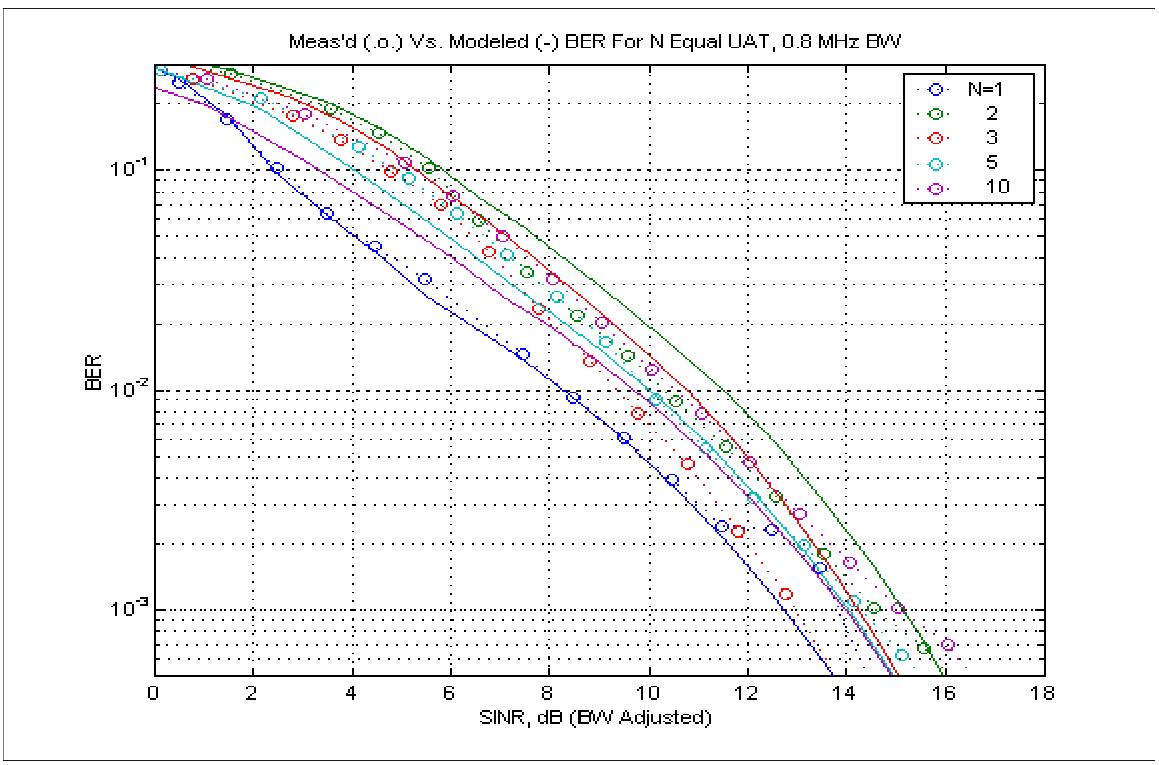

Figure 10. N Equal UATs, INR >> 0, 0.8 MHz Receiver

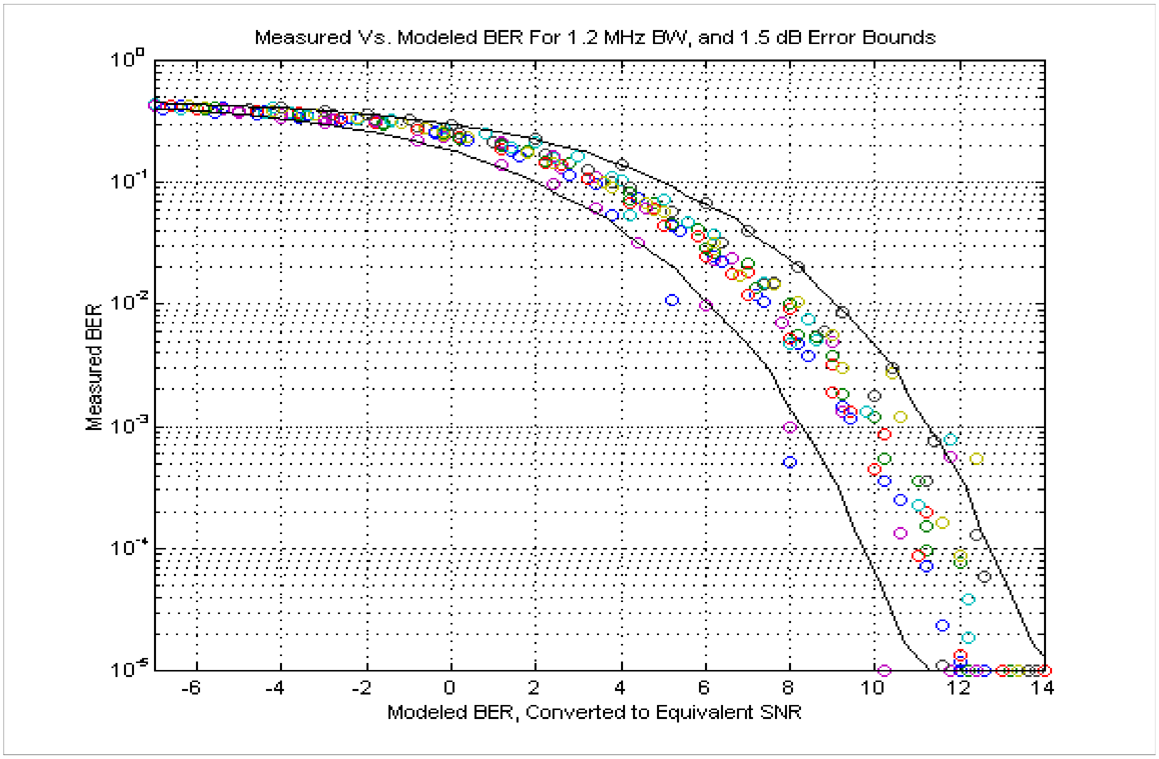

Figure 11. Model Errors for All Data, 1.2 MHz Receiver

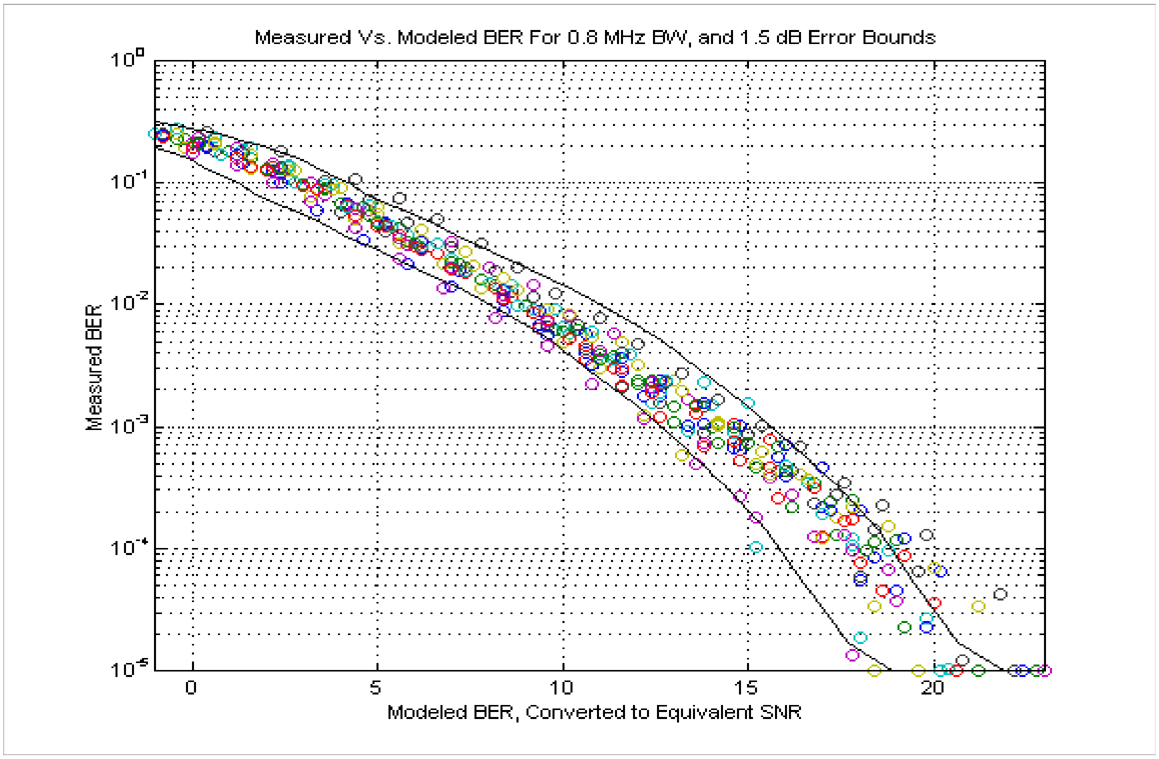

Figure 12. Model Errors for All Data, 0.8 MHz Receiver